N-jettiness as a Jet Algorithm

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Originally implemented in 1108.2701 with Ken Van Tilburg
Code development with Chris Vermilion (now in FastJet Contrib)
Preliminary studies with Iain Stewart and Frank Tackmann

April 5, 2013 — Snowmass @ BNL

Uses of N-(sub)jettiness

N-jettiness: τ_N as global jet veto

[Stewart, Tackmann, Waalewijn: 1004.2489]

N-subjettiness: τ_N/τ_{N-1} for N-prong substructure

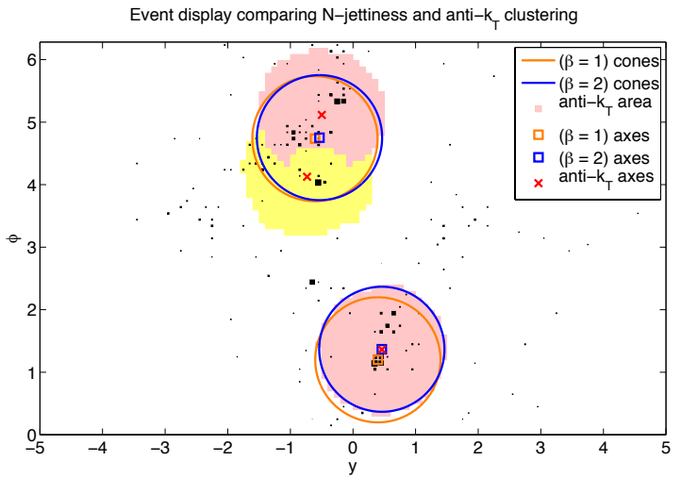
[JDT, Van Tilburg: 1011.2268 & 1108.2701]

As a Jet Algorithm: Identify jets by minimizing τ_N

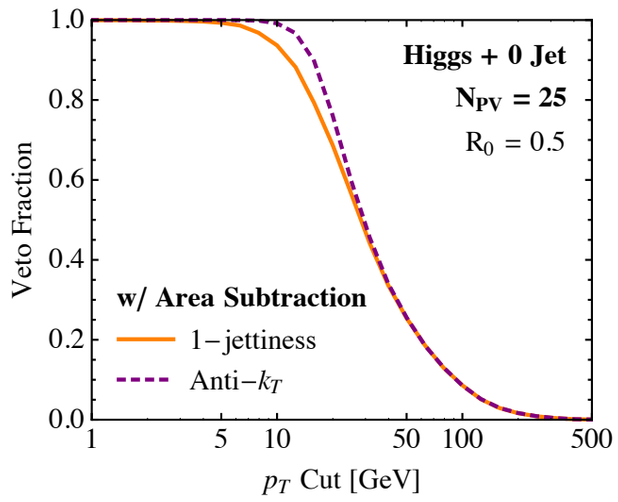
[JDT, Van Tilburg; Stewart, Tackmann, JDT, Vermilion in progress]

Today: Exclusive Higgs + N jet σ from
p_T veto on (N+1)-th jet from (N+1)-jettiness

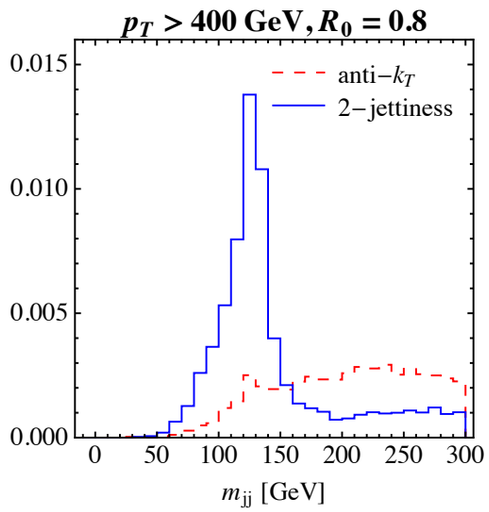
N-Jettiness as a Jet Algorithm



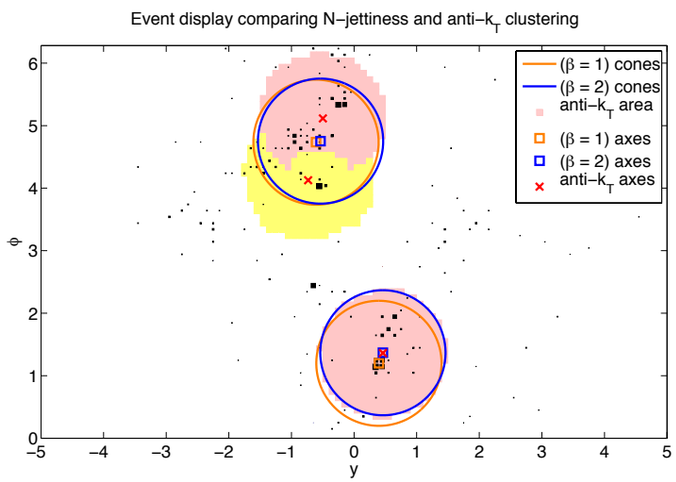
N-Jettiness
as a Jet Algorithm



Comparison to Anti-kT
for Exclusive Higgs σ



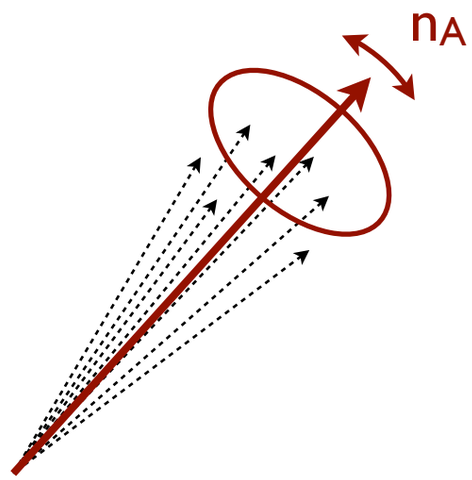
2-Jettiness for
Boosted Higgs



N-Jettiness as a Jet Algorithm

1-Jettiness as a Jet Algorithm

1-jettiness minimization: Stable cone finding!



$$\tau_1(R_0) = \sum_k p_{Tk} \min(\Delta R_{A,k}, R_0)^2$$ ← Key!

in the jet — outside the jet

Minimize over axis: $p_{\text{jet}} = \sum_k p_k$ in cone [Ellis, Huston, Tönnesmann]

Usual cone algorithms:
Find all stable cones (local minima of τ_1)
Apply split/merge criteria

(see also "Optimal Jet Finder" [Grigoriev, Jankowski, Tkachov], Jet Energy Flow Project, k-means clustering algorithm, ...)

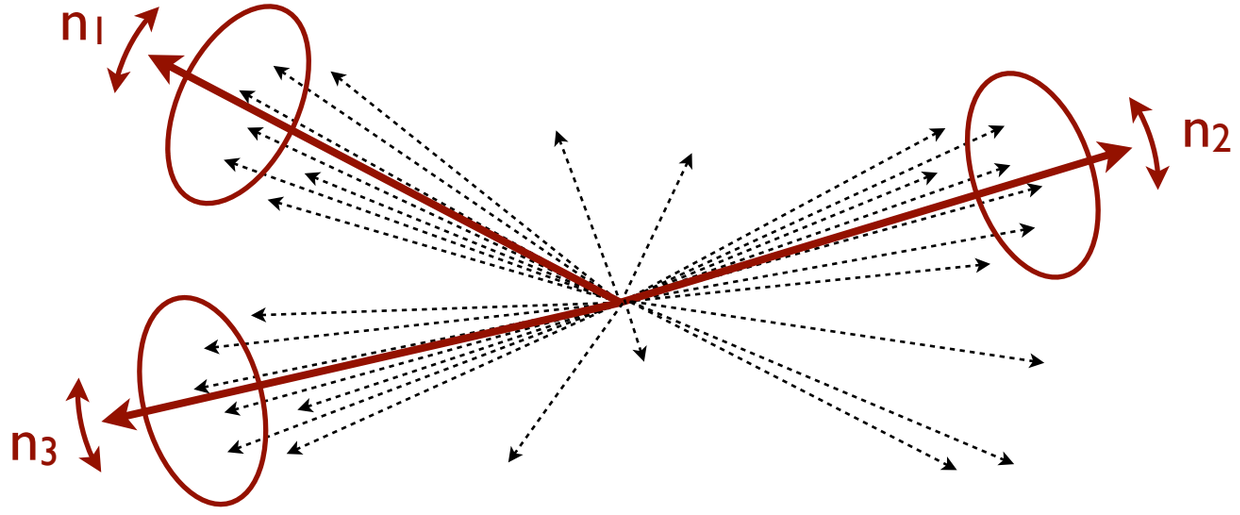
N-Jettiness as a Jet Algorithm

N-jettiness: choose axes n_i to minimize τ_N

Adjustable Exponent

$$\tau_N^{(\beta)}(R_0) = \sum_k p_{T,k} \min\{\Delta R_{1,k}, \Delta R_{2,k}, \ldots, \Delta R_{N,k}, R_0\}^\beta$$

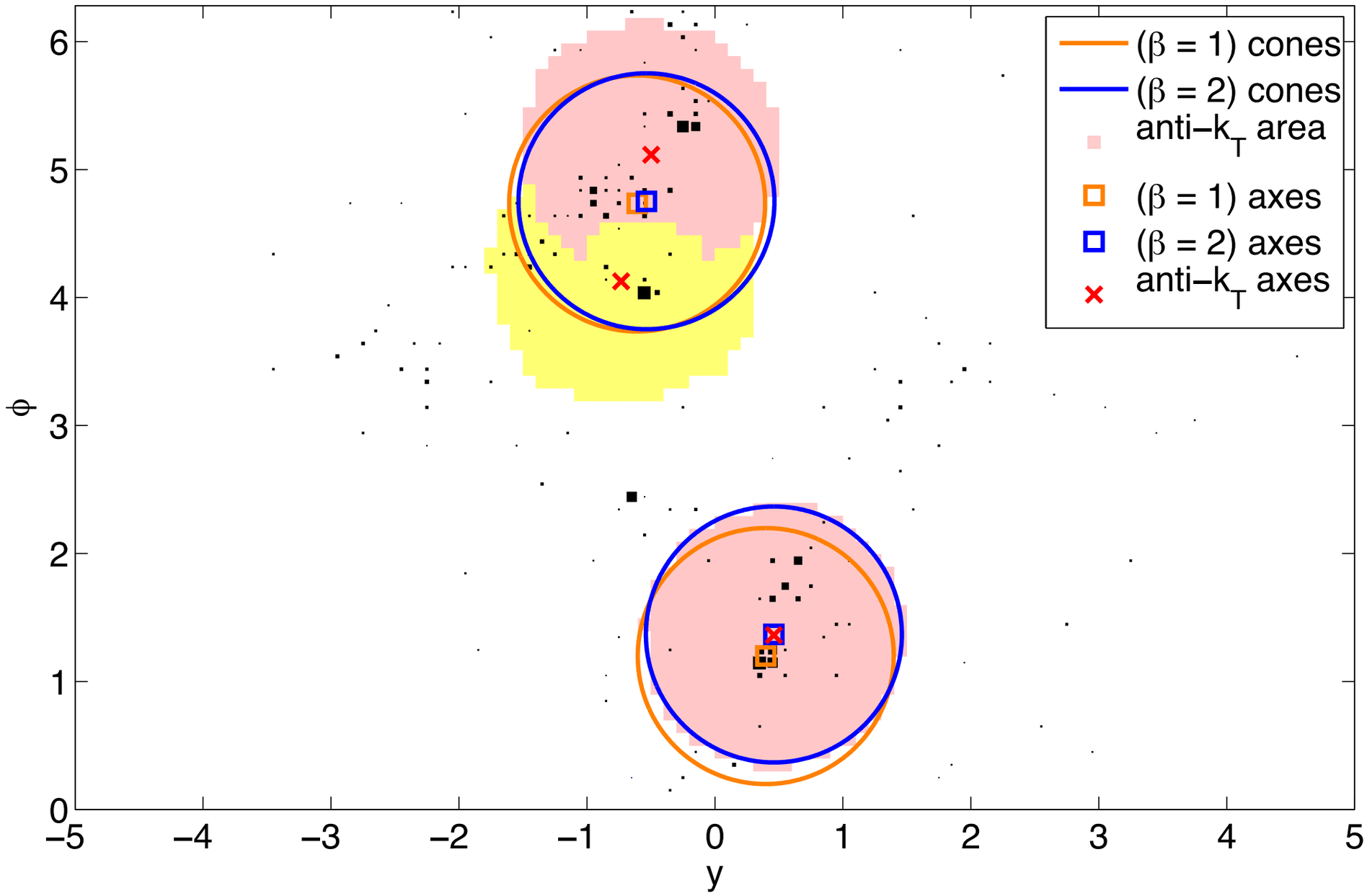
in jet 1 | in jet 2 | in jet N | outside



Identifies exactly N jets, no split/merge needed

[Reasonably fast algorithm for $1 \leq \beta \leq 3$ in 1108.2701; available from FastJet Contrib]

2-Jettiness Jets



β = 1: Jet Axis ≠ Jet Momentum
β = 2: Jet Axis = Jet Momentum

Good for checking jet systematics?

[JDT, Van Tilburg: 1108.2701]

Generalizing the Measure

$$\tau_N = \sum_k \min\left\{\rho_1(p_k),\ \rho_2(p_k),\ \ldots,\ \rho_N(p_k),\ \rho_{\text{beam}}(p_k)\right\}$$

Jet regions from competition

Today: Perfectly Circular Cones

[Available from FastJet Contrib for $1 \le \beta \le 3$]

$$\rho_{\text{beam}} = p_{T,k}\,(R_0)^\beta$$

$$\rho_{\text{i}} = p_{T,k}\,(\Delta R_{k,i})^\beta$$

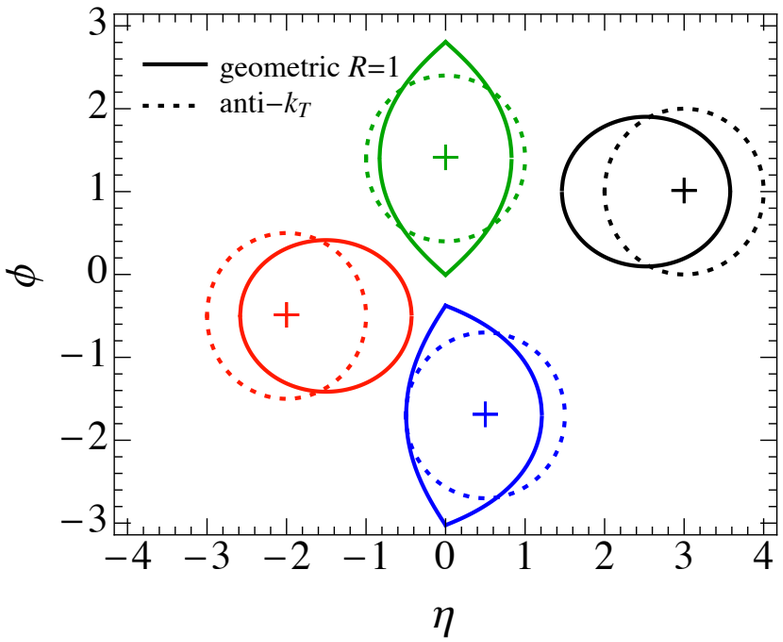
Eventually: Calculationally-Friendly Cones

$$\rho_{\text{beam}} = \ldots$$

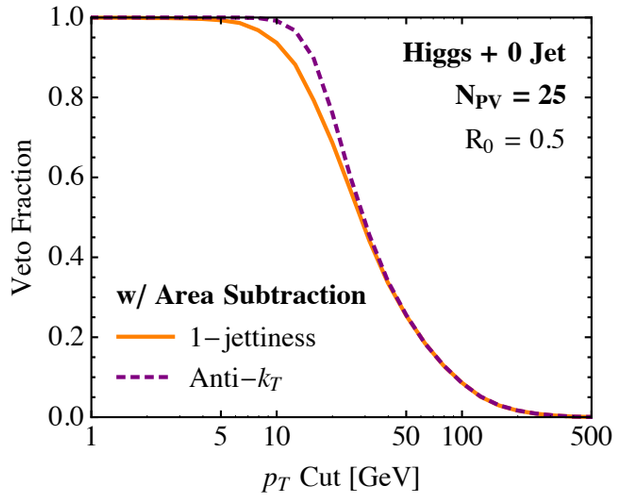
$$\rho_{\text{i}} = \ldots$$

"Geometric E Measure"

(Calculationally-Friendly Footballs)



[Jouttenus, Stewart, Tackmann, Waalewijn: 1302.0846]



Comparison to Anti-k_T for Exclusive Higgs σ

Two "Cone-like" Algorithms

Anti-k_T:

Arbitrary # of jets

N-jettiness:

Exactly N jets
(exclusive cone algorithm)

For well-separated jets:

N-hardest anti-k_T = τ_N minimization

In jet overlap regime ($\Delta R < R_0$):

Must Merge Jets

Can Split Jets

In noisy environment:

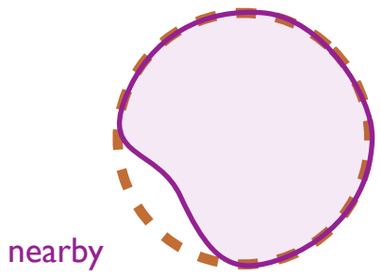
"Nibbling Effect"

Always πR^2 area
(up to jet overlap)

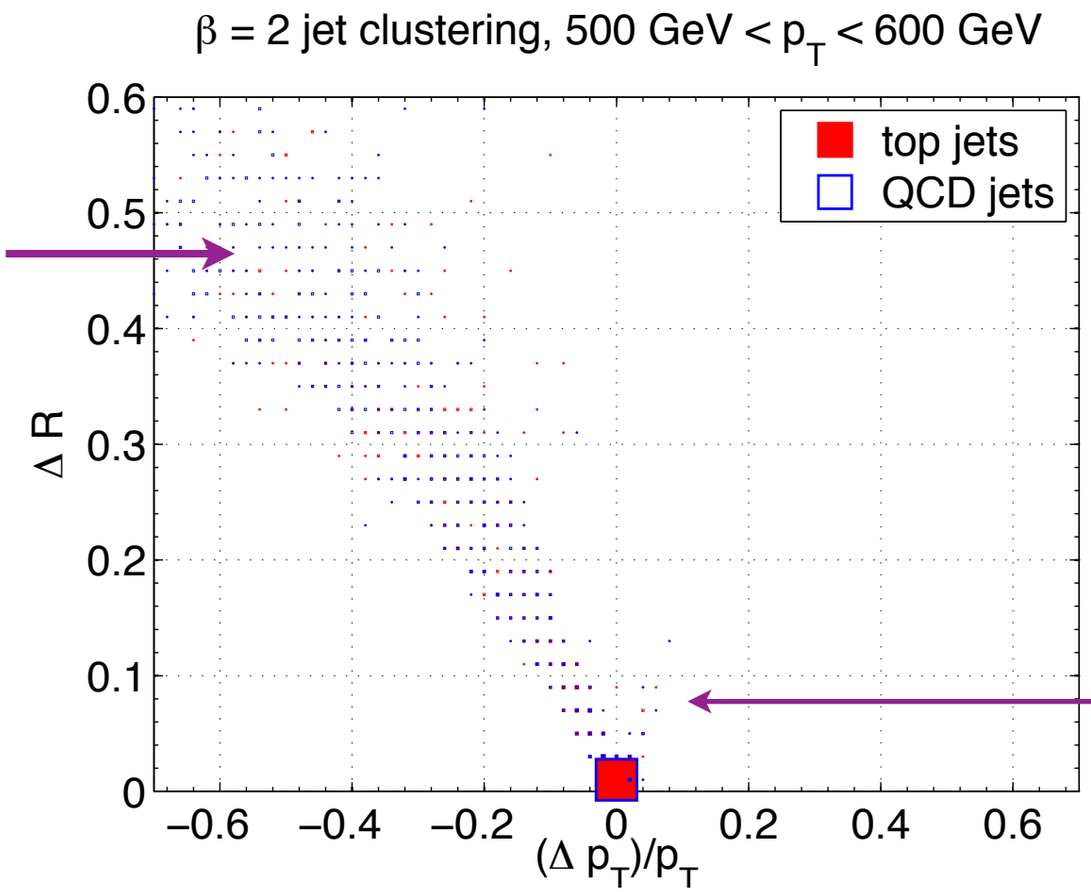
High-p_T Events

BOOST 2010 Samples (R = 1.0): Anti-k_T vs. 2-jettiness ($\beta = 2$)

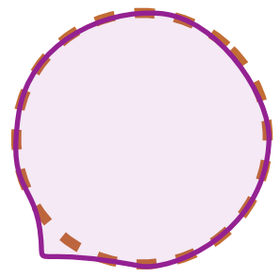
Anti-k_T
"Nibbling Effect"



(Some recovery possible with CMS "wide jets")



[JDT, Van Tilburg: 1108.2701]

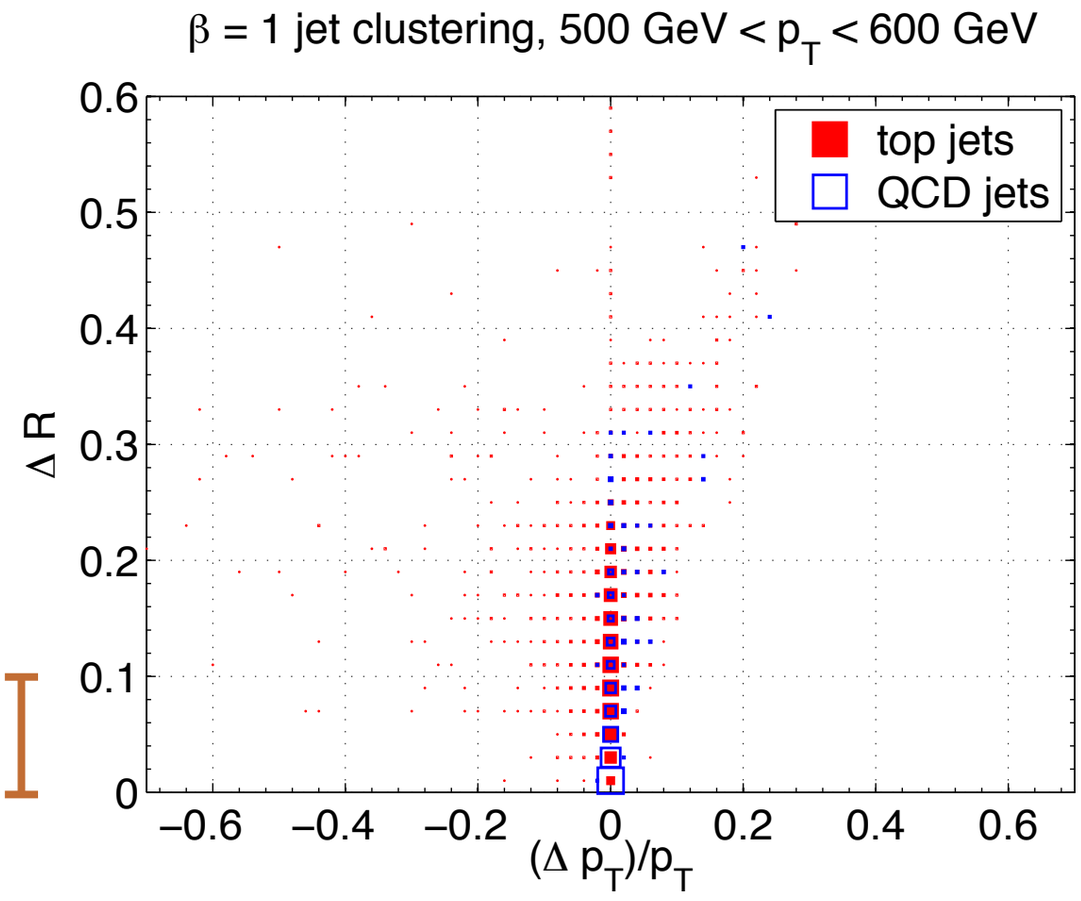


"Anti-Nibbling"

Nearly Identical Jets ≈ 93% match hardest jet
e.g. for QCD dijets: ≈ 81% match two hardest jets

Effect of β

BOOST 2010 Samples (R = 1.0): Anti-kT vs. 2-jettiness (β = 1)



[JDT, Van Tilburg: 1108.2701]

≈ 90% of dijets within ΔR = 0.1

ΔR as jet quality criteria?

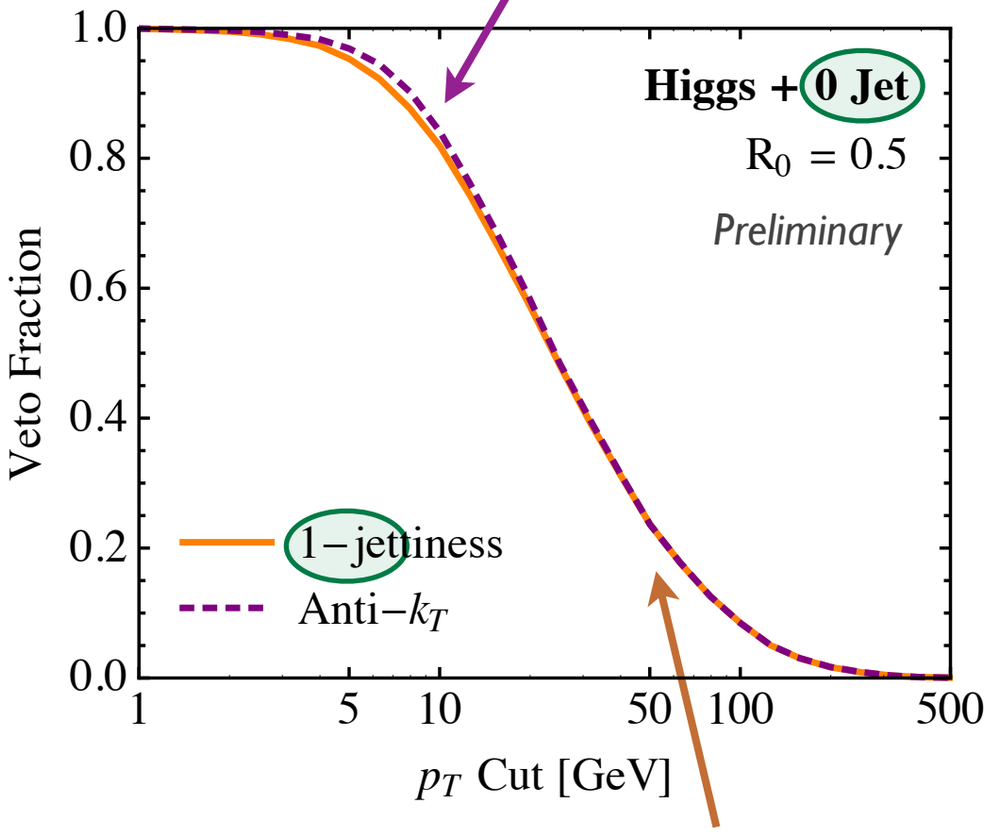
β = 1: "Median axis" Less sensitive to contamination

β = 2: "Mean axis" Jet axis = Jet momentum (like anti-k_T)

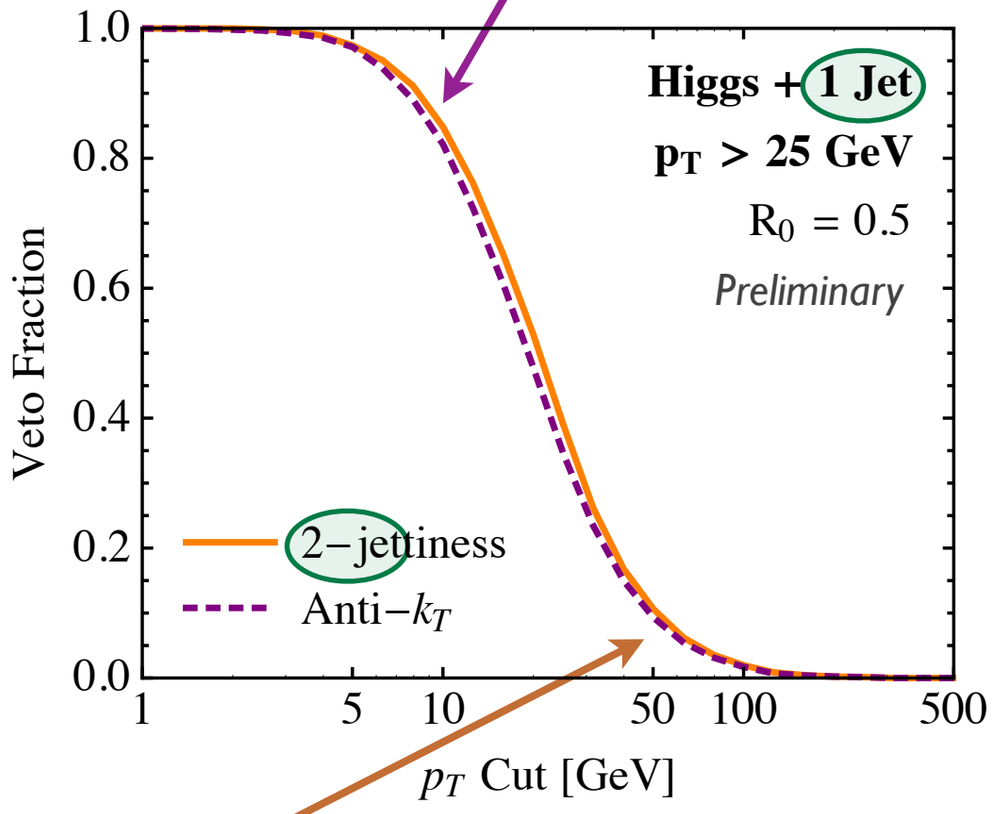
Exclusive Higgs + N jet σ

p_T veto on (N+1)-th jet from anti-k_T vs. (N+1)-Jettiness

Anti-Nibbling



Subtle Boundary Effects



Difference small at high p_T

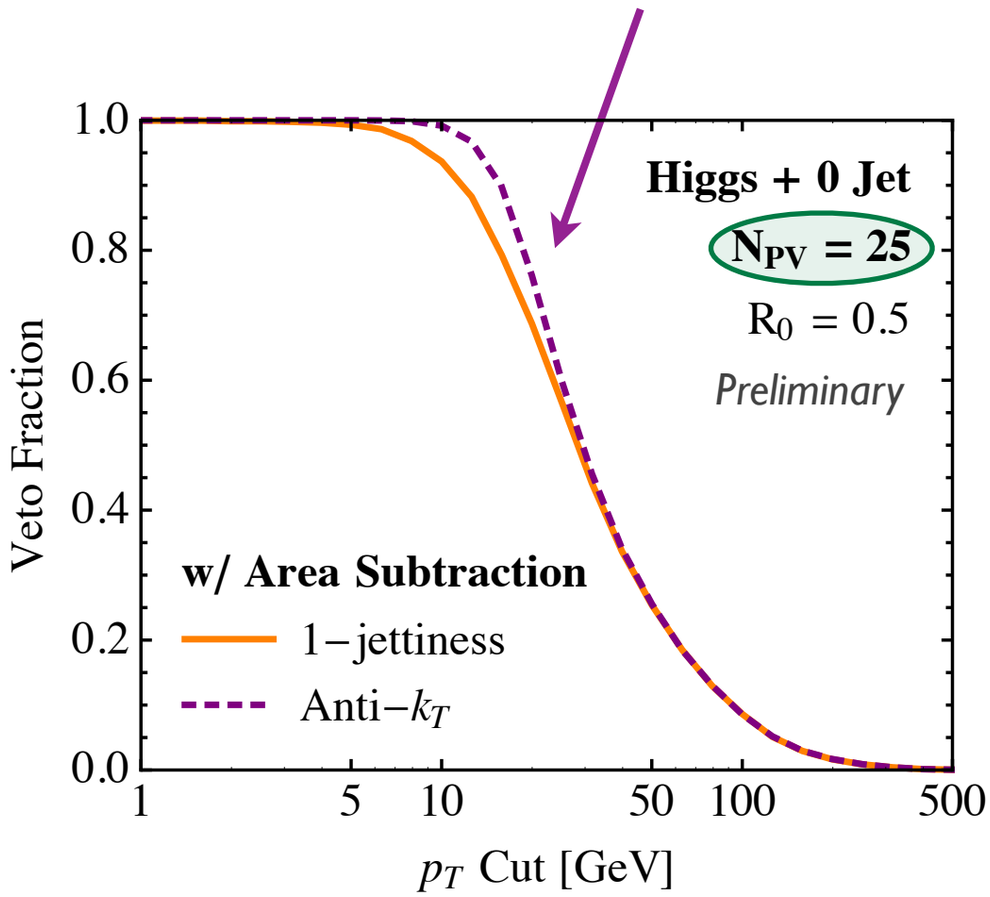
Pythia 8 (default tune, R = 0.5)

[See backup slide for original use of τ_N as veto]

Impact of Pileup

1-jettiness: Always one cone of area πR^2

Anti-k_T: (anti-)nibbling more pronounced in noisy environment



Jet p_T corrected with area subtraction
[Cacciari, Salam,Soyez]
Jet boundary not corrected using this method

Questions for Audience:

What degree of
Jet Energy Scale systematic
from (anti-)nibbling?

Is it N_{PV} dependent?

Pythia 8 (default tune, R = 0.5)

Bottom Line

N-jettiness: Well-suited to analyses with fixed N

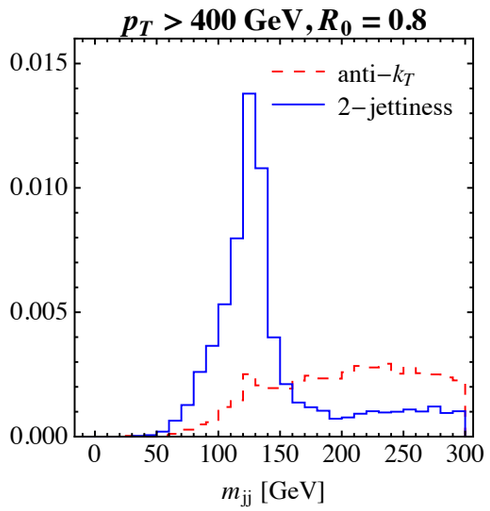
Trade offs in e.g. exclusive Higgs + N jet σ:

Computational Speed (Anti-k_T) vs. Perfect Cones (N-jettiness)

Open question: Theory uncertainties?

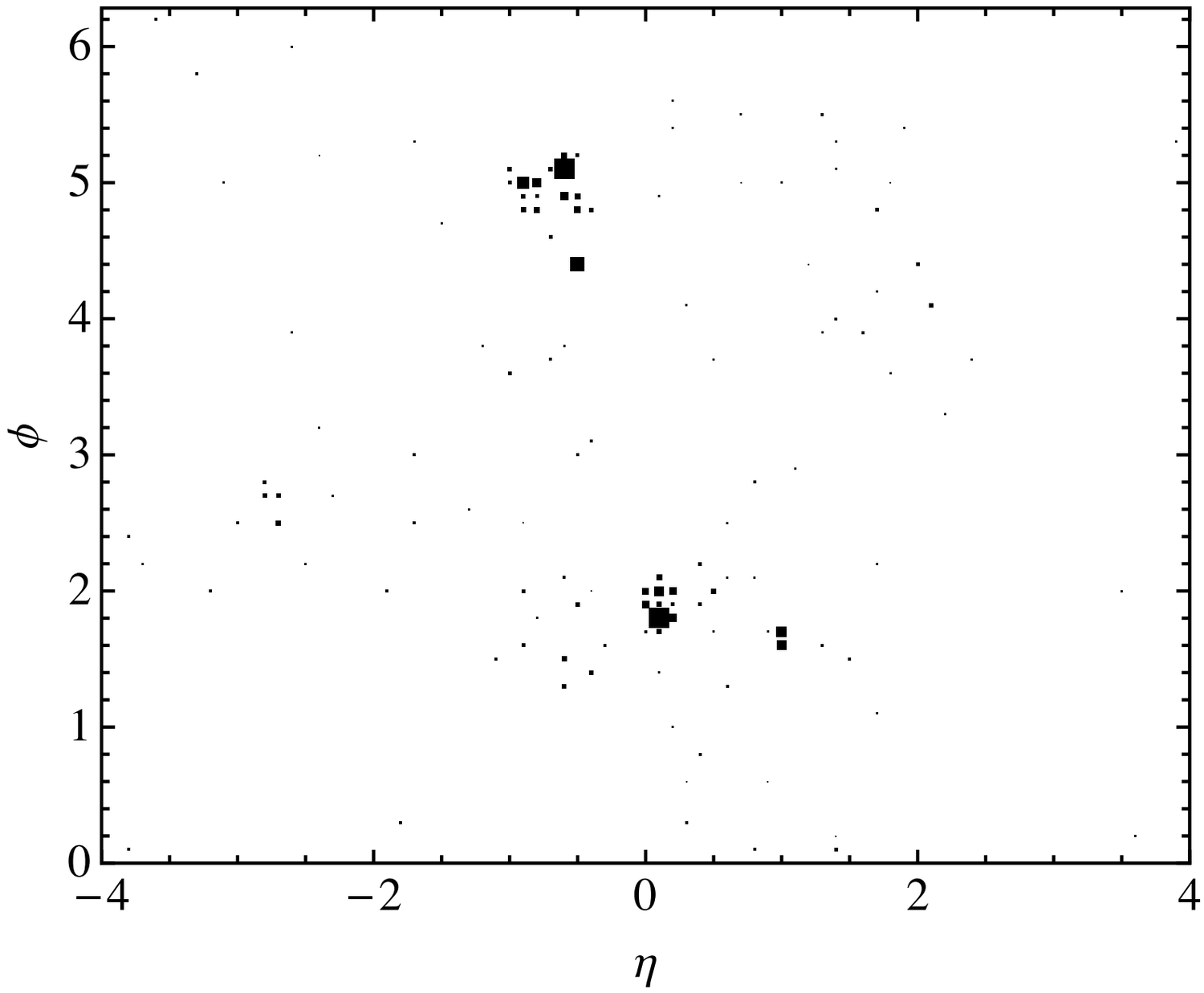
Algorithmic subtlety:

Current code uses (anti-)k_T as starting point to find local minimum of τ_N
Fast, reliable, well-defined, and IRC safe. Better option?
[Global minimum of τ_N impractical: $O(k^{2N+1} \log k)$ for k particles]



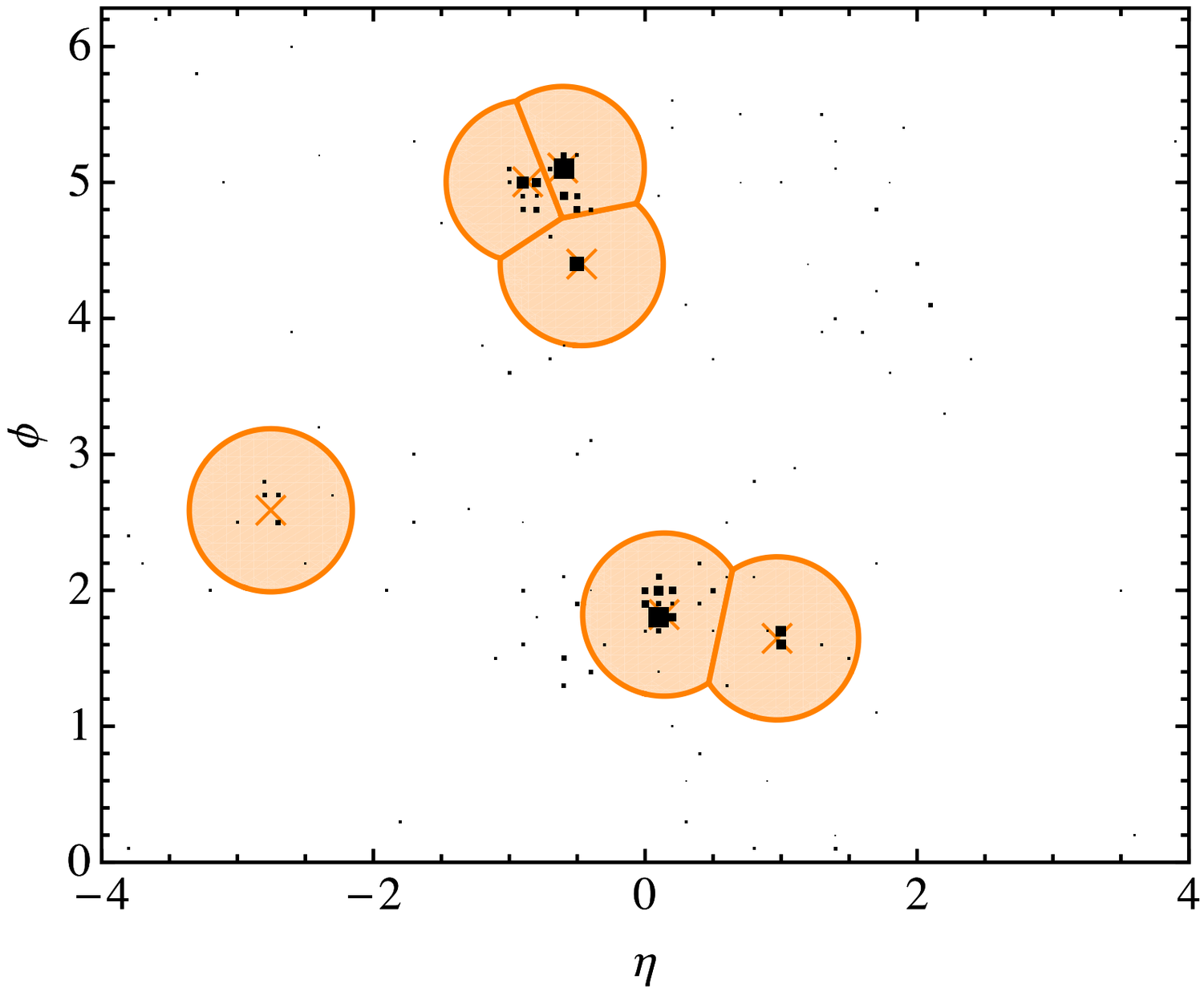
2-Jettiness for Boosted Higgs

Intelligent Partitioning



[In progress:
Stewart, Tackmann, JDT, Vermilion]

Intelligent Partitioning



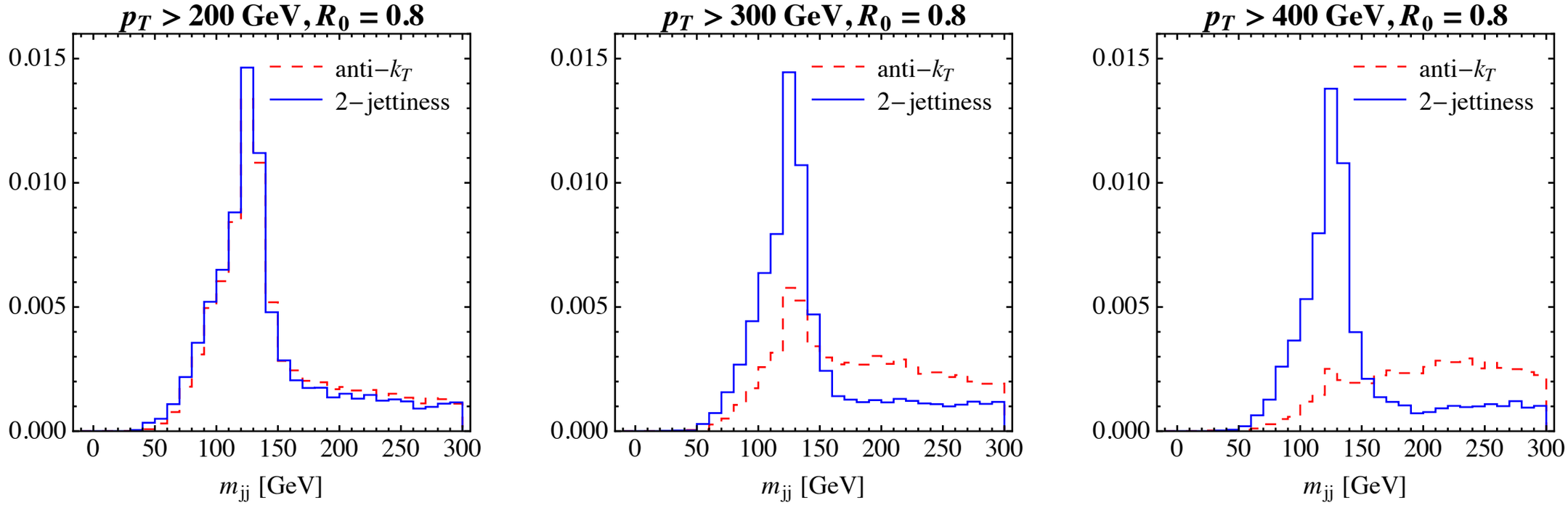
[In progress:
Stewart, Tackmann, JDT, Vermilion]

Interpolating the Higgs?

The Boosted Higgs Search

$$q\bar{q} \to Z^* \to ZH \begin{cases} \hookrightarrow b\bar{b} \\ \hookrightarrow \ell^+\ell^- \end{cases}$$

$$p_T^{\text{merge}} \simeq \frac{2m_H}{R_0}$$

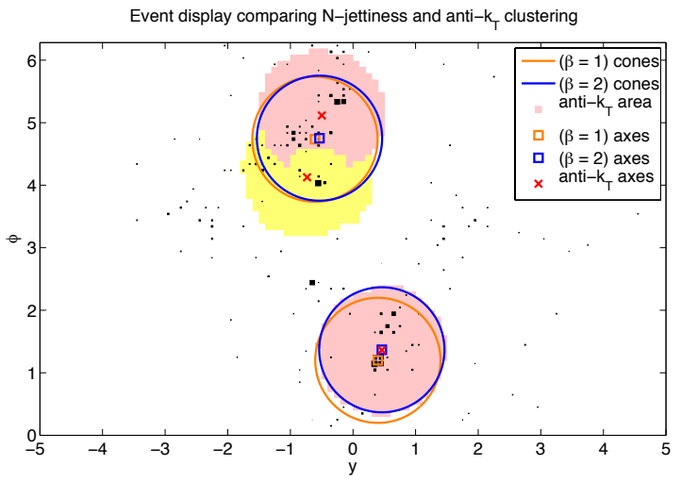


Signal: Two hardest anti-k_T vs. 2-jettiness

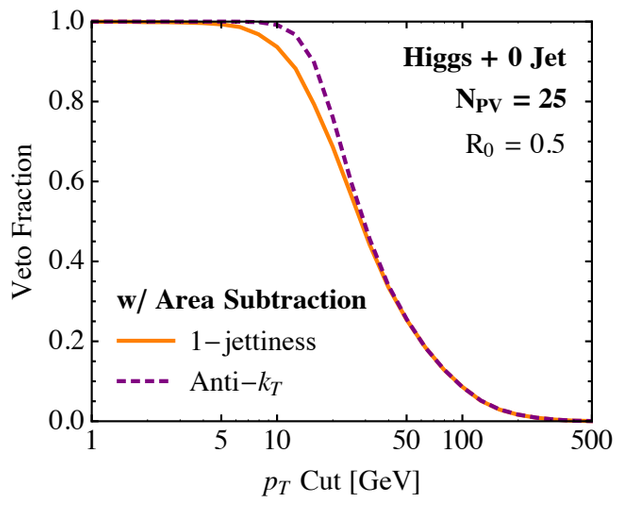
N-Jettiness as a Jet Algorithm

$$\tau_N = \sum_k \min\left\{\rho_1(p_k),\ \rho_2(p_k),\ \ldots,\ \rho_N(p_k),\ \rho_{\text{beam}}(p_k)\right\}$$

Three Choices: Jet Measure, Beam Measure, Axes (e.g. minimization)



N-Jettiness as a Jet Algorithm



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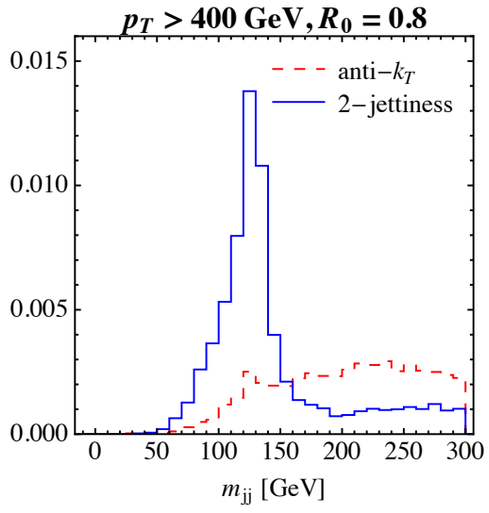

2-Jettiness for Boosted Higgs

[JDT, Van Tilburg; Stewart, Tackmann, JDT, Vermilion in progress]

Backup

Exclusive Higgs + N Jet σ

Signal with N desired jets, veto extra jets

Two Operating Modes with τ_N

Original N-Jettiness Paper

Identify N jets
with e.g. N-jettiness

Global jet veto with τ_N

Theoretical Advantage
(global observable)
=
Experimental Disadvantage
(sensitivity to 4π, though ways to mitigate)

N-Jettiness as Jet Algorithm

Identify N+1 jets
with (N+1)-jettiness

Local p_T veto on (N+1)-th jet

Experimental Advantage
(nearly identical to anti-k_T)
=
Theoretical Disadvantage
(non-global observable, though ways to mitigate)